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8. The fibres that hold an innovation network:¹ an analysis of knowledge-sharing in the Glare network

Elco van Burg, Erik van Raaij and Hans Berends

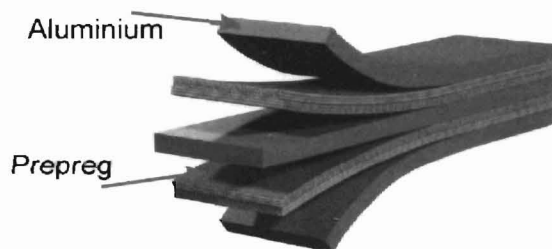
During the 1950s, failure of aircrafts due to material fatigue was becoming a nightmare. In 1954, two De Havilland Comets crashed. Investigation of the wreckage of the first Comet established metal fatigue as the cause. Aluminium, the metal commonly used for the skin of aircrafts, is fairly susceptible to fatigue. Fatigue cracks can cause weaknesses in the aircraft structure, which can result in accidents. Aircraft need to be inspected frequently for fatigue cracks, corrosion and impact damage. These inspections and repairs, if needed, are very costly because the aircraft cannot be operated at that time. The failure of aircrafts, due to metal fatigue, encouraged aircraft manufacturers to improve their structures. Strengthening the structure by adding more aluminium leads to heavier aircraft, however, which results in higher fuel costs.

In a search for solutions to fatigue, corrosion, and impact damage, aircraft manufacturers and research labs started to look for new materials. Different directions were promising. In the 1950s and 1960s, composites emerged as a new class of materials: modern fibres such as carbon, aramid and glass embedded in plastics. This class of materials is almost insusceptible to fatigue and is relatively light. However, composites are brittle and have less favourable impact properties than aluminium. The possibilities of improving the aluminium alloy itself, the second option, were only limited. The third direction was explored by the Dutch aircraft manufacturer Fokker, the Dutch aerospace laboratory NLR and the Delft University of Technology (TU Delft). They examined the combination of the good properties of aluminium with those of composites. Together with industrial partners like Alcoa, Akzo and 3M, they developed the sandwich material Glare. This material is built up from layers of aluminium and fibres (see Box 8.1). A part of the research was funded by the Dutch government, through NIVR, the Dutch agency for aerospace programmes. After more

BOX 8.1 GLARE®

Glare is an aircraft material built up from thin layers of aluminium bonded together with adhesive containing embedded glass fibres (prepreg). Its major application is in the fuselage of Airbus super-jumbo A380. The material has several advantages, compared to the 2024-T3 aluminium alloy (Vermeeren, 2003; Vogelesang, 2003). First, the material has remarkably reduced and slower crack growth, about 10 to 100 times slower than in aluminium alloys. As a consequence, inspection of the structure for fatigue is not really necessary during the operational life of the aircraft. Second, the residual strength of Glare after multiple site damage is significantly higher. Third, the impact resistance is higher because of the high strain rate strengthening phenomenon in the glass fibres and the relatively high failure strain of the fibres. Fourth, the weight of the material is approximately 10 per cent lower than aluminium. Fifth, the flame resistance is extremely good. All in all, this means that aircraft can be designed with less material, and less need for inspection, thus saving costs.

The relatively high production cost of the laminates is the main disadvantage. These high costs are primarily caused by the complex and labour-intensive production process.



Source: Picture: TU Delft.

than 30 years of development and testing. Glare was eventually applied to the Airbus A380 mega-liner, as the first large-scale application of a fibre-metal laminate to an aircraft fuselage (the body of the aircraft).

The Glare network can be characterized as a network with continuous collaboration centred on a single innovation. The level of involvement of the individual partners constantly changed over time, as did the

composition of the network. But Fokker, TU Delft and NLR always stayed together. The goal of this collaboration was to develop fibre-metal laminates, first Arall and later Glare, and to get these applied to aircraft. This innovation is explorative in its nature, as it is a new aircraft material and involves new concepts of manufacturing, designing and applying these materials.

In the network, TU Delft had a central role as the initiator of the research and the knowledge centre. Later on, the role of the knowledge centre was taken over by a joint venture of Akzo and Alcoa, named Structural Laminates Company (SLC), succeeded by the Fibre Metal Laminates Centre of Competence (FMLC). Airbus and Stork Fokker AESP had a more central role in managing the network when the application of Glare to the Airbus 380 materialized. Despite the presence of three core network partners (TU Delft, Fokker, NLR), there was no central authority that could exert power over all the other network members.

We find that in a decentralized network like this, the motivation problem is the main challenge. The knowledge that has to be shared in this network is mostly tacit, and is often core knowledge for the network partners. A striking conclusion is that the free-riding problem is not found, probably because the continuity of the collaboration bounded opportunistic behaviour by network members.

Seven solutions are found that enable knowledge-sharing in this network. These are, in order of importance: interpersonal relationships, agreements on value distribution, direct communication, network density, absorptive capacity, printed and electronic media and goal alignment. Interpersonal relationships were very important to motivate partners. These relationships created a network identity, thus improving commitment and motivation, and probably preventing any free-riding. Second, agreements were important to create commitment to engage in development. Finally, direct communication was important in establishing interpersonal relationships and as an opportunity to share knowledge. The solution concepts are, however, not without risks. Relationships are vulnerable because relationships can be harmed by personal tensions, and personnel change could sever interpersonal ties between organizations. Formal rules and agreements can exclude certain parties from knowledge-sharing, thus possibly cutting off innovation opportunities.

In the remainder of this chapter we will first describe the historical development of the Glare network. Subsequently, we analyse knowledge-sharing in this network. We present an overview of the knowledge-sharing problems and discuss the solution concepts that were applied. Finally, we conclude this analysis by discussing interesting findings.

THE HISTORY OF THE GLARE NETWORK

Period I: Early History (1971–1981)

The philosophy of Glare and its predecessor Arall rests upon two techniques: bonding and laminating. The first idea stems from the Dutch and British aircraft manufacturers Fokker and De Havilland. These companies used to build aircrafts by bonding the wooden parts. This idea was subsequently applied to metal, and Fokker applied their first bonded metal wing structure in the Fokker F-27 in 1955. The second technique, laminating materials, also stems from the manufacture of wooden aircrafts. Fokker introduced the first laminated wing structure in 1916. Laminating multiple layers of plywood provided an opportunity to use different fibre orientations, arranging them in such a way that the directional strength of the material was optimized. This technique is also applied in Glare, where the fibres run in different directions.

In the first two decades after the Second World War, Fokker started looking for ways to improve the fatigue properties of metal structures. This kind of research was carried out in cooperation with NLR and also with TU Delft. The industrial needs of Fokker drove the research. Special research projects were funded by the NIVR and qualified testing was done by NLR. Fokker, TU Delft and NLR formed a close triangle in development, research and education (Figure 8.1).

This research at Fokker resulted in the bonded metal structure of the F-27. Fatigue tests indicated that the fatigue properties were good. In 1971, Fokker and TU Delft started studying reinforcements of bonded aluminium structures with fibres, an idea they had seen at NASA during a visit to the US. But this research did not show promising results, so the idea was

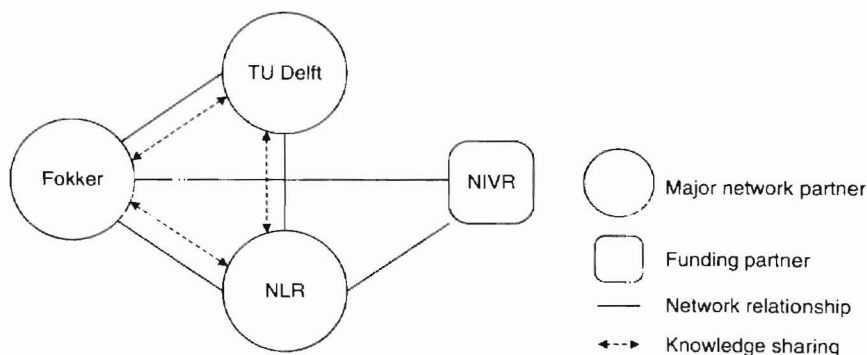


Figure 8.1 Early history of the network (1971–1981)

officially abandoned by Fokker's R&D management. Some people at Fokker, like Paul Bijlmer, still believed in the possibilities. He tried to continue the research contrary to the management's decision, but was forced to stop. At the individual level, however, some Fokker employees continued their cooperation with the people at TU Delft.

Researchers at TU Delft were convinced that fibre-metal laminates could have better fatigue properties than aluminium alloys. These researchers included the group around Professor Schijve (who was the former head of the Structures and Materials Department at NLR) and Vogelesang (who later became Schijve's successor as a professor in Delft). This group initiated a research programme on laminated sheet materials, which resulted in a new kind of material, called Fibre-Metal Laminates (FMLs).

One of the first projects was carried out by a graduate student, Roel Marissen, who finished his thesis in 1980. Using the framework he developed in his thesis, the research group was able to optimize the aluminium sheet thickness, the types of fibre and the fibre volume fraction. This resulted in thinner aluminium sheets, and for the fibre, aramid was chosen. Tests on this improved laminate showed that the material had excellent fatigue performance. The key to this is the 'crack bridging' mechanism of the fibres. Fibres remain intact under fatigue loading, whereas the aluminium cracks. The research at TU Delft thus resulted in a new material, which they called 'Arall' (Aramid Reinforced Aluminium Laminates) (de Vries, 2001: 2; Vlot, 2001: 43).

Period II: Network around Arall (1981–1991)

Inspired by the promising results for Arall, TU Delft continued its research on fibre-metal laminates and looked for industry collaboration and funding. Because the management of Fokker was not interested in fibre-metal laminates at that time and because specific material knowledge was needed, TU Delft looked for other industrial partners. Industry involvement was especially needed for the supply and knowledge of strong fibres and thin aluminium sheets. Vogelesang got the Dutch chemical company Akzo interested in providing aramid fibres. The first step Akzo took was to acquire the rights of the Arall patents that were filed in January 1981 by TU Delft with Vogelesang and Marissen as inventors. Akzo, in return, supported the research in Delft with a grant of 100 000 guilders a year, by providing equipment and materials, and by giving access to their lab.

By the end of 1981, a second industrial partner had become involved. Through existing contacts at TU Delft, the American aluminium producer Alcoa became interested in the new material. Alcoa was willing to supply the thin aluminium sheets needed for Arall, although manufacturing these thin

sheets was difficult and required a lot of work. But Alcoa was concerned that composites would replace aluminium in the future, and with Arall they could both supply their aluminium *and* play a role in the market for composite materials. Alcoa received a five-year exclusive licence to produce Arall, and launched the first commercial version of Arall in 1983. The third company to become involved was 3M, which supplied the 'prepreg' for bonding the aluminium sheets and the fibres. Unlike Alcoa and Akzo, 3M was not a development partner, but just a supplier of the adhesive.

Despite the lack of interest in FMLs, Fokker was still an obvious industrial partner in the development because of the long relationship between TU Delft, Fokker and NLR. Therefore, the different parties tried to get Fokker involved. First, NIVR asked Fokker to play a more active role in Arall applications. In 1984, this request resulted in an Arall working group with representatives from TU Delft, Fokker, NLR and NIVR. A wing panel for the existing Fokker F-27 could be developed and tested. First studies on the application of Arall on an F-27 wing had already been carried out by two students of Jan Willem Gunnink at TU Delft. This marked the first involvement of Gunnink in the development of FMLs. It was remarkable, certainly at that time, that Delft had designed the wing panels and had even made the production drawings according to Fokker specifications, so that Fokker could easily produce the panels. Delft also designed all kinds of detailed test specimens and tested them. So Fokker could test the larger size panels including the full-scale panel. The development of this wing was funded by NIVR, the first time TU Delft received direct funding from NIVR. This sparked a new era in which the role of TU Delft moved from basic research towards development and testing, directly funded by the government.

Tests on the full-scale F-27 panel again showed the excellent properties of Arall for fatigue and damage tolerance. As a result, TU Delft tried to convince Fokker to use Arall in one of their aircrafts. In 1984, however, Fokker decided not to use Arall in its new F-50. According to Daan Krook (former member of the board of directors of Fokker), Fokker would develop the F-50 with a 'minimum change configuration' from the existing F-27. Therefore, a major change like applying Arall instead of aluminium was out of the question. The good results of the F-27 wing project nevertheless prompted Fokker to ask NLR to get more involved in the project, which the people at TU Delft felt was an attempt to by-pass their involvement (Vlot, 2001: 71). TU Delft was upset by this behaviour of Fokker and told Fokker that it would continue with Akzo, Alcoa and 3M as primary partners. So the relationship between TU Delft and Fokker became strained. Individual relationships between people at Fokker and TU Delft were stronger than the official dispute, and people on both sides continued

to be involved in the project and remained on speaking terms and cooperative, because they personally believed in the material and in the need for cooperation. But Arall was never applied to a commercial F-27, mainly because it was too expensive to qualify as the new material for an existing aircraft.

Roel Marissen, one of the inventors of Arall, moved to the German aerospace research institute DFVLR (later called DLR). This created links between DFVLR and Alcoa, NLR and TU Delft. However, DFVLR never had a real role in the development of Arall because Marissen was working in other directions than the people at TU Delft. The industrial partners in the Arall network limited knowledge-sharing between people at TU Delft and Marissen at DFVLR because they were concerned about leaking core knowledge in the direction of their German competitors.

The skies looked bright for Arall, but soon some clouds would show up. In 1987, Alcoa opened an Arall plant in Pittsburg (PA). Knowledge about the material properties of Arall originated from TU Delft and was integrated with the production knowledge of Alcoa. Shortly after the opening of the Arall production facility, an Arall conference was held in Seven Springs (PA). At this conference, the 'jury of the international aviation community' was present and the TU Delft community presented excellent results for Arall at the conference. Off-stage, however, Geert Roebroeks, a Ph.D. student from TU Delft, had discovered some disappointing Arall properties and the group at TU Delft had already started working on a solution with glass fibres as an alternative to aramid. Marissen, who was still working on Arall in Germany, had also found that aramid fibres around a crack would break under the cyclic loading conditions that occur in fuselages. Marissen was upset about the fact that his role in the development of Arall was not acknowledged by the people from TU Delft. He therefore decided to mention the detrimental properties in his presentation in order to thwart, as he saw it, the development of Arall. The publication of some disappointing results and the attempts of the people at TU Delft to develop an alternative material harmed the image of Arall to some extent. The aviation community, however, became convinced that the principle of the material was promising, which created space for the acceptance of an improved material (Vlot, 2001: 78).

The new variant of the material, with glass fibres, did not have the detrimental properties of Arall, and TU Delft concentrated on further development of this material, which they called Glare (GLass Aluminium REinforced). A patent on this new material was filed by Akzo in October 1987 and was finally accepted in 1991. At the same time, Alcoa had introduced its first commercial Arall products and had managed to get a first application of Arall in the cargo door of the McDonnell Douglas C-17

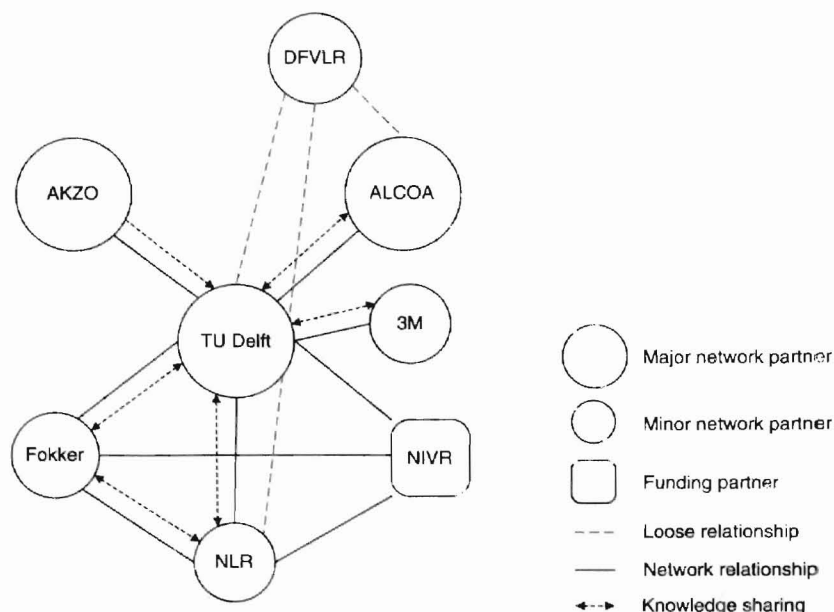


Figure 8.2 Network around Arall (1981–1991)

military transport aircraft in 1988. The complete network at this period is shown in Figure 8.2.

Period III: Network around Glare (1991–2001)

While Alcoa had its first commercial Arall application, the relationship between Alcoa and Akzo deteriorated. The exclusive production rights that Akzo had licensed to Alcoa were expiring. Akzo was losing interest, but thanks to Daan Krook's lobbying with the Akzo management, they continued to be involved, and started a Glare business. Akzo wanted to set up a joint venture with Alcoa for both Glare and Arall because this would possibly give Akzo opportunities to sell fibres to the aerospace market. But Alcoa was not willing to have this joint venture, and the relationship became strained. Furthermore, a Dutch lobby at the international aerospace community for Glare, consisting of people from Akzo and TU Delft, harmed the commercial position of Arall. Alcoa finally decided to go along with Akzo and Glare. This resulted in a joint venture, Structural Laminates Company (SLC), in 1991, which owned the patents. Akzo owned one-third and Alcoa two-thirds of this joint venture. The partnership company SLC, located in

the US, was responsible for the commercialization of Glare and Arall. On the Dutch side, the subsidiary of SLC, Structural Laminates BV (SLBV), was located in Delft and was supposed to do research and technical marketing.

Although there was a promising new material, there was still a long way to go. The goal was to get FMLs on a new aircraft type. The first challenge was to test and qualify the material. Another challenge was to achieve the acceptance of the aviation industry. A major disadvantage for the aviation industry was the high costs of Glare, which were at that time up to 10 times higher than aluminium. Production was labour intensive and difficult. A major breakthrough came in 1993 when the concept of splicing was developed. With splices, Glare panels can be wider than the size of the metal sheets they are made of. These wider panels significantly reduce the installation costs of Glare.

Various aircraft construction companies developed an interest in the material. First, in 1988, people at MBB (which later became a part of Airbus Germany) read an article about Arall by Vogelesang and considered it to be a promising material. These people were responsible for testing a segment (called a 'barrel') of the Airbus A330 and A340. They were able to test new materials too, and they asked TU Delft to produce a Glare test panel for the barrel. With funding from Akzo, TU Delft could get Fokker to produce the panels. The tests were performed in 1990 and the results were good. The people at Airbus Germany (the current name) continued testing Glare for different applications during the 1990s.

A second company with an interest in Glare was Boeing. In 1990, Glare was selected for a cargo floor in the Boeing 777 because of its excellent impact properties. In 1993, Rob van Oost from SLC was sent to Boeing to study the application of Glare on the successor of the 747 Jumbo Jet. Because the requirements of this new plane frequently changed, he finally studied application in the already existing Boeing 777. Although the results looked promising, Boeing decided not to use Glare for the primary structure of the 777.

While industry interest grew, Alcoa was frustrating the people from SLC who tried to sell Glare to the aircraft industry. During the 1990s, the policy of Alcoa regarding Glare had changed. First, Arall was not a commercial success, and therefore their Arall plant was operating at a loss. Second, Glare was more and more seen as a competitor for their aluminium, because it was targeted at the same fuselage market. Strategically, they wanted to prevent the application of Glare and therefore they obstructed the commercialization of Glare through SLC, sometimes by preventing SLC people from talking to decision-makers at aircraft construction companies, at other times by giving inadequate or inaccurate information. The reason why Boeing decided not to use Glare, in spite of good test results,

was in part a result of Alcoa's behaviour. Bill Evancho (at that time, head of SLC) believed that the salespeople from Alcoa convinced Boeing not to use Glare. In 1993, this finally resulted in a moratorium on Glare studies, set by the management of Boeing.

While this closed the door to Boeing, interest from other sides grew. The third organization that became interested was the US Air Force. A US Air Force officer had heard about Arall and started his Ph.D. study on Glare at TU Delft in the early 1990s. On his return, he convinced the US Air Force to use Glare for fuselage repairs of the C-5A Galaxy transporter (Vlot, 2001: 130, 131; Scholtens, 1995). Besides this programme, the US Air Force also evaluated Arall for a rudder, for flaps and for dorsal covers.

A fourth company with an interest was Bombardier Aerospace. In 1996, they decided to use Glare for a part of the Learjet 45 business jet. The fifth company was Garuda Airlines (Indonesia) who used Glare for a panel of an Airbus A330 (Vlot, 2001: 138). And subsequently, in April 1999, an experimental Glare fuselage panel was installed on a German Luftwaffe A310. Furthermore, US Airways used Glare in a cargo bay floor, and Galaxy Scientific Corporation used Glare in an explosion-hardened container.

Also Aérospatiale (later Airbus France) became involved. In 1994, Buwe van Wimersma was sent to Toulouse by SLC. He studied the application of Glare to the A330. Later, in 1997 and 1998, he and his colleague Gise Wit became members of the Large Aircraft Division led by Jens Hinrichsen. They prepared information about Glare to convince him to apply it. This eventually resulted in the choice of Glare for the fuselage of the A3XX which later became the A380.

The group at TU Delft needed extra funding for the increasing number of tests and experiments. The Dutch government saw the need for a strong push to Airbus, helped by the lobbying efforts of Krook, Gunnink and Vogelesang. They funded half the costs of the A310 panel and also allocated in total about 30 million euros to the Glare project in the period 1997 to 2003, which was coordinated by the NIVR. This funding was used to start the Glare Technology Program (GTP, later Glare Research Programme, GRP), in which TU Delft, SLC (later SLI and FMLC), NLR, Airbus and Stork Fokker AESP were involved. Later, a significant part of the money was also used to get Glare tested in the mega-liner barrel test, a huge fuselage section similar to the A380. This test began in 2001 and the panels are still being studied today. These tests were performed at Airbus Germany, but NLR engineers were involved in these tests as well. Through this involvement, they learned about Airbus's test methods and results.

Alcoa considered Airbus's growing interest in Glare as a threat to their core business, the production of aluminium. They convinced Akzo to shut down the production facility of SLC, formally because of low customer

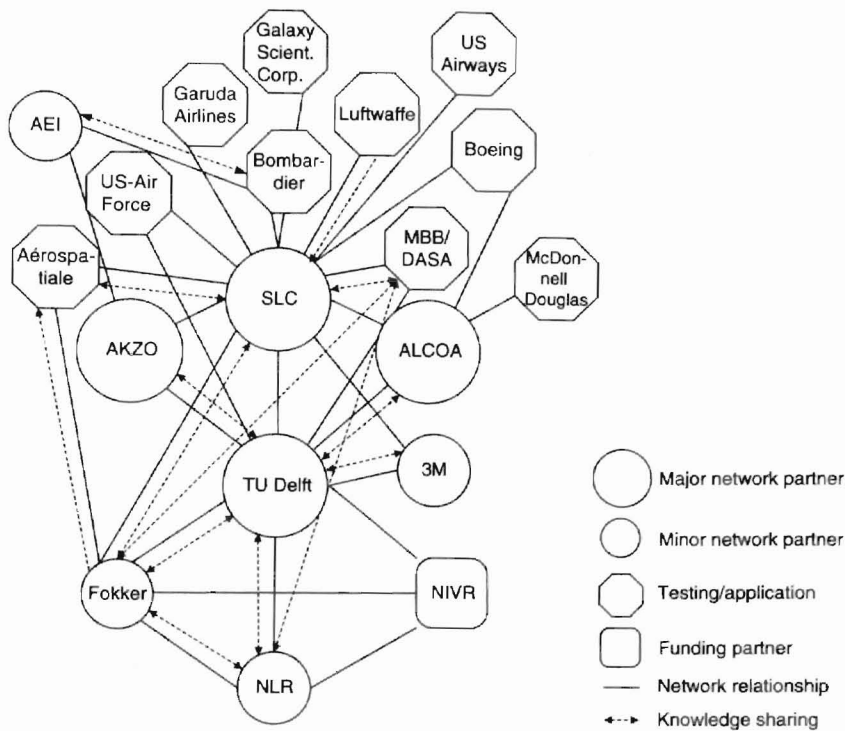


Figure 8.3 Network around Glare (1991–2001)

interest. Alcoa stopped supplying thin aluminium sheets and the production of Arall and Glare was stopped in 1997. As a result, McDonnell Douglas and Boeing needed aluminium replacements for respectively the cargo door of the C-17 and the cargo floor of the Boeing 777. The commercial activities of SLC were stopped as well. Alcoa just kept SLC alive to keep control over the patent rights. A licence for secondary applications was given to Aviation Equipment, Inc. (AEI). They were successful in the application of Glare to hardened containers and aircraft cargo bay floors. They also provided Glare for the Learjet 45 and supported Bombardier in their fibre-metal laminates R&D programme. The entire network for the period 1991–2001 is depicted in Figure 8.3.

Alcoa eventually withdrew and the joint venture SLC was broken up. At first, Akzo continued its Glare activities. With the help of Daan Krook (who was a board member of SLC), Akzo acquired licences for Glare in Europe. Akzo restructured SLBV to Structural Laminates Industries (SLI). But shortly after that, Akzo reconsidered the fit of SLI with the core

business of Akzo. They decided to sell SLI because they could not produce the material, they did not supply the specific glass fibre that was used in Glare and their core activities were not in the aerospace sector. As a result, in 1998, Akzo sold SLI to Stork Aerospace.

At Stork Aerospace, SLI became incorporated in Fokker AESP. Fokker AESP consisted of what was left of Fokker, which had gone bankrupt in 1996. So, after years of low commitment on the part of Fokker, the 'new' Fokker became heavily involved again. With the incorporation of SLI in Fokker AESP, Fokker finally got a licence for the production of Glare.

Period IV: Airbus and Future Glare (2001–)

As Alcoa and Akzo withdrew from the network, interest from Airbus (which resulted from a merger in 2001 between aerospace companies in Germany, Spain, England and France) grew. They became convinced of the excellent properties of Glare after an exciting lobbying period. In particular, the opportunity for weight reduction persuaded them. In 2001, the Heads of Agreement for application of Glare in the A380 was signed with Stork Fokker AESP, who would be producing the material. But the industrialization of Glare was still at an early stage. Stork Fokker AESP quickly started building a manufacturing plant, industrializing Glare and qualifying the production process according to aerospace norms. The plant was built in Papendrecht, The Netherlands, and was officially opened in November 2003, although production had already begun in 2002. Airbus also wanted to acquire the knowledge and capability of manufacturing Glare and opened a plant in Nordenham, Germany, to manufacture five of the 27 Glare panels. The knowledge about Glare properties required for these production facilities was mainly obtained from people from the former SLC, now working at FMLC and Stork Fokker AESP.

To get the material ready for the manufacture of the first A380, the parties worked closely together. The design of Glare parts and development of the design principles occurred in close cooperation between Stork Fokker AESP and Airbus. These companies also jointly developed production and improved the material further. This resulted in a new generation of Glare, with improved strength, called HSS Glare. For the qualification of the material, NLR, Stork Fokker AESP, FMLC, TU Delft and Airbus worked closely together to demonstrate the quality of the material and to perform all tests. TU Delft, with its very enthusiastic group of students and employees, performed tests that showed which fields needed more testing or even further improvement and which fields had been tested satisfactorily. The qualification testing was subsequently done by NLR, according to the norms in aerospace.

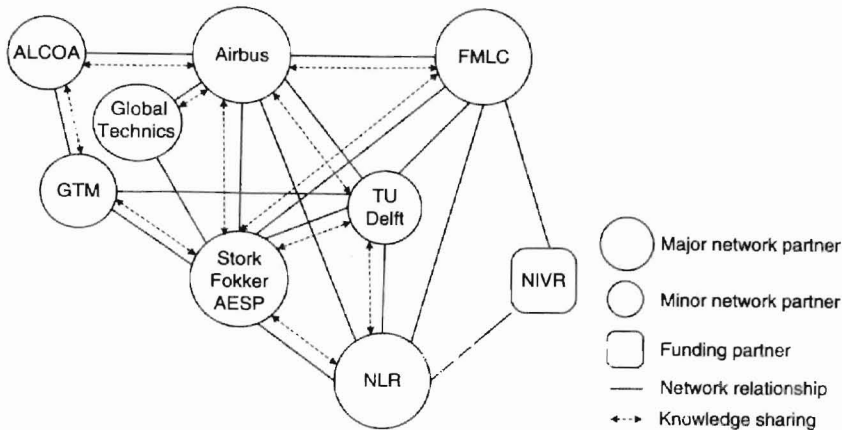


Figure 8.4 Network Airbus and Glare (2001–)

To continue research on the material and to provide knowledge about Glare to the network partners, a Glare centre of competence was established. This centre, Fibre Metal Laminates Centre of Competence (FMLC), was founded by TU Delft, NLR and Stork Fokker AESP in 2001. This centre also had the task of exploring different applications of Glare. Another task was to distribute the funding from the NIVR and the government. But because Airbus became fully involved in the development of Glare, the necessity for external funding decreased. In 2003, also due to policy changes by the Dutch government, funding was reduced to a minimum. The managing director of FMLC was Jan Willem Gunnink. But, by the end of 2004, following a dispute over policy, Gunnink left FMLC and started a new company named GTM. Almost all the employees from FMLC joined this new company. GTM is currently, among other projects, developing new materials and structures, which include improvements to aluminium structures. One of their clients is Alcoa, which again has expressed interest in the development of FMLs and is also cooperating with Airbus on developments around Glare and laminated aircraft materials.

Besides GTM, another small new company appeared, GlobalTechnics (see Figure 8.4 for the network as of 2001). Gise Wit, Adel Khoudja and a third partner founded this enterprise. They provide knowledge and experience of Glare to the network and perform calculations on Glare. Their main clients are Stork Fokker AESP, Airbus, and Airbus partners.

Table 8.1 lists the main events in the development of Glare. Thirty years may seem like a long time for such an innovation to come to fruition. One reason for the long development path is the fact that extensive material

Table 8.1 *Main events in 30 years of Glare development*

Year	Event
ca. 1978	Professor Boud Vogelesang develops fibre-metal laminates (FML) at TU Delft, building on two decades of collaboration between Fokker, TU Delft and NLR.
ca. 1981	Involvement of Akzo, Alcoa and 3M in the development of an aramid fibre reinforced FML product: Arall.
ca. 1984	Jan Willem Gunnink leads Arall tests on Fokker F-27 wing panel.
1987	Alcoa opens Arall plant; Arall material properties questioned at Seven Springs conference; Akzo files first patent for a new, glass-fibre-reinforced FML product: Glare.
1990	Glare tested at Boeing; first Glare tests at MBB (later: Airbus Germany); further tests at MBB continued through the 1990s.
1990–1999	Various small-scale applications of Glare at Bombardier, US Air Force, German Luftwaffe and others.
1991	Glare patent accepted; Alcoa-Akzo joint venture (SLC) for Arall and Glare established.
1993	Technological breakthrough ('splicing') enables more efficient production of Glare.
1994	Buwe van Wimersma (from SLC) studies Glare application at Aérospatiale (later: Airbus France).
1996	Bankruptcy of Fokker; Stork Fokker AESP established.
1997	Buwe van Wimersma and Gise Wit (both from SLC) seconded to Airbus to study application of Glare to the Airbus A3XX mega-liner.
1997	Glare Technology Project (GTP) established, funded in part by the Dutch government. Partners include TU Delft, SLC, NLR, Airbus, Stork Fokker AESP.
1998	Alcoa withdraws from SLC; Akzo restructures SLC into SLI, which is eventually sold to Stork Fokker AESP.
2001	Start of the mega-liner barrel tests at Airbus Germany.
2001	Heads of Agreement signed between Airbus and Stork Fokker to produce Glare for the A380 mega-liner fuselage. Stork Fokker and Dutch government invest in Glare production capability.
2001	TU Delft, Stork Fokker and NLR establish fibre-metal laminate centre of competence (FMLC).
2002	Glare production started in Papendrecht and Nordenham.
2003	Airbus takes full control of Glare developments related to the A380 and thereby limits the role of other partners like FMLC and TU Delft.
2004	Two new start-ups established for further development of Glare: GTM, by Jan Willem Gunnink, and GlobalTechnics, by Gise Wit and two partners.
2005	First Airbus A380 prototype takes off with a 350 m ² Glare fuselage section.

qualifications are necessary before a new material can be applied to any aircraft structure. A second reason is that aerospace manufacturers will generally only make an investment in a new material when they design a completely new type of aircraft. This has severely limited the number of windows of opportunity for Glare. With only a limited number of sufficiently large aerospace manufacturers in the world, the developers of Glare had to make sure that the right people at such companies were convinced of the superior properties of Glare just as plans for a new aircraft type were being developed.

KNOWLEDGE-SHARING PROBLEMS IN THE GLARE NETWORK

The development of fibre-metal laminates, eventually leading to the production and application of Glare, started as a loose cooperation between Fokker, NLR and TU Delft. Over time, the network expanded and the level of involvement of partners changed. Problems and tensions between partners came and went. Over the years, the partners in the network had to create, share, and integrate knowledge related to material properties, materials testing, aerospace requirements, design knowledge and production knowledge. Some of this knowledge could be codified and shared 'on paper'; other knowledge was of the tacit kind. All this knowledge-sharing took place without a core network player orchestrating the process or a *grand design* for knowledge-sharing. Yet, in spite of various knowledge-sharing problems between network partners, and the lack of explicit knowledge management to solve these problems, the goal was eventually achieved: the first Airbus A380 super-jumbo took to the air in April, 2005 with 350 m² section of Glare panels in its fuselage. What is the story behind this success?

To unravel this story, we will first discuss the four general knowledge-sharing problems and subsequently pay attention to the solutions, as they appeared in this case study. In the Glare network, the main knowledge-sharing problems were those related to efficiency and motivation. These problems were tackled through interpersonal relationships, agreements on value distribution and sanctions. These solution concepts are the most salient and provide an explanation of the successful knowledge-sharing in spite of the lack of a grand design of knowledge management.

Motivation

The motivation of partners to share knowledge is very important. In the Glare case, motivation was not a problem generally. Various individuals

acted as passionate inspirers, motivating others to stay involved and share knowledge. Professional pride and a passion for fibre-metal laminates facilitated knowledge-sharing in the network. But, at times, competition, conflict, and personal pride would negatively influence motivation. The relationship between TU Delft and Fokker was not always without problems, for instance. They repeatedly argued about who invented Arall. Fokker would give presentations about Arall without naming TU Delft as the inventor. There would also be competitive strife about who should receive funding from NIVR; the industrial partner Fokker, or the academic partner TU Delft. This caused recurring conflicts between Fokker and TU Delft, although these were sometimes more moral than formal conflicts (Vlot, 2001: 72, 73). Such conflicts decreased the motivation of the partners to cooperate with each other. After the bankruptcy of Fokker in 1996, the problem largely disappeared because the people involved in the initial conflict were no longer working at TU Delft or Fokker.

Issues caused by personal pride and personal 'battles for competence' were the second driver behind the motivation problem. This problem first appeared in the relationship between NLR employees and people from TU Delft. The very enthusiastic Vogelesang came to NLR with his new material and NLR performed tests on the material. But the people at NLR were sceptical and have more or less remained so ever since. This caused difficulties in the relationship. The tensions between Marissen and the people from TU Delft were also about personal pride. And in the last phase of the development, knowledge-sharing between Fokker AESP and Airbus Nordenham was less optimal because people saw it as a 'battle for competence', thus creating a situation where it would be a weakness to ask the other for help.

Finally, the competitive strategies of firms in the network also hindered the motivation to share knowledge. In the early years of Glare, Alcoa obstructed contacts between SLC and Boeing because they started to see Glare as a competitor to their aluminium. They were no longer motivated to turn Glare into a success. More recently, the motivation to share knowledge between Airbus-Fokker and other interested parties has been hindered by Airbus's concerns over knowledge leaking to Boeing.

Boundaries

In the Glare network, people from different organizations and from different backgrounds had to work together and share knowledge. Crossing the boundaries between different practices, cultures and organizations was sometimes difficult. In this case study, the two most influential boundaries

that had to be crossed were boundaries between cultures (both national and corporate) and between professional backgrounds.

The boundaries between cultures appeared for example in the relationship between TU Delft and NLR. This caused discussions about the demarcation of tasks. According to Vogelesang, this can also be interpreted as a tension between a professional research organization (NLR) and an educational institute without a qualified testing lab (TU Delft). Boundaries between national cultures were present between Alcoa and the Dutch partners, and between Airbus France and the Dutch partners together with Airbus Germany.

Knowledge-sharing was at times hampered because of boundaries between people with different backgrounds. Even when people had the same profession, for example researchers, it was hard to understand each other's results, because of the differences between the research areas and interests. For example, in the 1990s, when Fokker AESP and Airbus were asked to provide guidance on the developments at TU Delft, they lacked the appropriate knowledge to do this.

Efficiency

As the development of Arall and Glare progressed, the stock of knowledge accumulated, and more and more individuals became involved. This exacerbated the challenge of creating and sharing knowledge in an efficient way. The efficiency problem has two main causes: lack of industry leadership in development, and frequent change of personnel.

The first challenge was related particularly to the efficiency of *creating* knowledge. The developments at TU Delft did not always fit the needs of industry. More 'guidance' from industry was needed. But the industrial partners lacked the appropriate insight to see the way ahead or did not understand the priority of providing guidance. As a result, sometimes research was undertaken which was not very useful for the further development of FMLs. Gise Wit, who was involved in the cooperation of Airbus, TU Delft and Fokker, said: 'A lot of reports were very useful, but also a number ended up in the garbage can'. After a while, some individuals at Airbus were appointed to guide the research, but they often lacked appropriate knowledge and time to provide efficient guidance. Therefore, SLBV, later on SLI and in the last phase FMLC, took the lead in directing activities.

Second, the efficiency of knowledge-sharing was harmed by regular change of personnel in the network. At TU Delft, a lot of research in the lab was carried out by graduates. These former students usually worked very enthusiastically in the lab for about two years and then moved to a job elsewhere. When they did not end up working for one of the network partners,

the knowledge they acquired often disappeared from the network. According to Gise Wit, at that time working for Fokker: 'The knowledge rests with a limited number of people, because the others leave the network quickly. Of course, it rests with the permanent employees, like Ad Vlot and Geert Roebroeks. But Ad Vlot died, Boud Vogelesang left. . . . So, I think that the knowledge also seeped away to some extent.' On the other hand, graduates heading out to other companies within the network helped to disperse knowledge, thus improving efficiency.

Knowledge-sharing efficiency was not helped either by the frequent change in those attending GRP meetings. Some network partners did not acknowledge the important role of the GRP meetings for knowledge exchange and sent whoever was available to these meetings, thus forgoing the opportunity to build long-term relationships between team members.

The efficiency problem was never fully eliminated. Regular meetings and strong interpersonal relationships somewhat reduced this problem. In particular, the research programmes increased the efficiency of knowledge-sharing, because these established some sort of central coordination. Nevertheless, 10 (out of 17) respondents named the efficiency problem (also talking about the last phases), because it was a central issue in knowledge-sharing in the whole development trajectory.

Free-riding

In the Glare network, no clear instances of the free-riding problem were found. Sometimes, the danger of free-riding raised its head, as in 1986 when Fokker started negotiations with NLR to get them more involved in the development, while the centre of development was still at TU Delft. Fokker even questioned whether there was still a role for TU Delft. At TU Delft, they felt, however, that Fokker had 'hijacked' the Arall project without having put much effort into it before. Because Delft did not want to support this new direction, the attempt failed. Thus, the free-rider problem was tackled in a natural way. All respondents, looking back at the whole development trajectory, said that no partner profited more than their fair share considering their contributions. Some partners profited more than others, but they also took more risks and spent more effort and money on the Glare development. Because all partners were willing to cooperate for a long time, the free-riding problem did not occur. Within this long time frame, partners did not show any significant opportunistic behaviour. Another explanation for the prevention and reduction of the free-riding problem is the strong network identity among the core of the individuals involved. Such a network identity motivated them to share

knowledge, and created commitment (shared norms and beliefs) and trust, which prevented free-riding.

SOLUTIONS TO KNOWLEDGE-SHARING IN THE GLARE NETWORK

In the absence of conscious knowledge management in the Glare network, several solution concepts were applied more or less unconsciously that enabled and improved knowledge-sharing. An overview and illustration of the findings is presented in Table 8.2. Each solution concept is discussed in the following text, in order to provide more insight into their effectiveness in the Glare case. This discussion concludes with a graphical representation of the relationships between solution concepts and problems.

The Effectiveness of Interpersonal Relationships

The concept of interpersonal relationships is a solution that explains the success story of Glare to a large extent. Where organizations often considered their own aims and goals instead of the common good, the interpersonal contacts provided a strong informal network committed to the development of FMLs. This 'Glare community' was also a basis for trust. The informal network was an important enabler for knowledge-sharing in the network of organizations. When organizations practically withdrew from the network, individual engineers continued to be involved, carried on the development and shared their knowledge. Although organizations restricted knowledge-sharing, the engineers continued to share their knowledge, because of shared beliefs and passion for the material. These interpersonal contacts were created at conferences like the Arall conference, meetings within the aerospace field (Brite Euram programme, GRP, etc.), and last but not least through TU Delft graduates heading out into companies all over the world. Over time, the interpersonal network grew because more people became involved and more graduates swarmed out.

The solution concept of interpersonal relationships is, however, fairly vulnerable. When relationships break up because of conflicts or personnel change, the channel for knowledge-sharing between organizations disappears. For example, a conflict that occurred in the 1980s damaged the relationship between people at Fokker and people from TU Delft for a long time, creating Chinese walls between these groups and influencing knowledge-sharing. In the words of Adel Khoudja: 'In the past, there was a conflict between TU Delft and Fokker. I was part of Fokker. Much later, you could still not easily come back in the TU Delft group'.

Table 8.2 Overview and illustration of solution concepts

Solution concept	Subcategories	Examples
Interpersonal relationships		Adel Khoudja (Fokker, GlobalTechnics) had good relationships with people at Airbus and with Gise Wit and Geert Roebroeks. Jan Willem Gunnink had good relationships with Jens Hinrichsen, Bill Evancho, Daan Krook and Boud Vogelesang.
Agreements on value distribution	Agreements, knowledge protection rules, knowledge-sharing rules, property rules	TU Delft with Akzo, Alcoa and 3M; SLC; GRP; Barrel test; Airbus with Fokker AESP; MOU of Airbus.
Direct communication	Co-location, conferences, frequent communication, meetings, site visits, social events, team working, training	GRP teams who worked on assigned Glare-related developments. The Large Aircraft Division at Airbus in Toulouse (co-located) where SLC people and Fokker (AESP) people were involved. Arall conferences (Seven Springs, 1987 and TU Delft, 1988) and Glare conferences with presentations for researchers, aircraft manufacturers and aviation companies. Frequently held GRP meetings. NLR engineers who visited the barrel test. People from TU Delft visiting Airbus's production facilities and design teams. Milestone events for the people involved in GRP. Design trainings held at Airbus.
Network density	Knowledge brokers	FMLC functioned as a formal knowledge institute, brokering knowledge of involved partners. There were contacts at Airbus, who were responsible for bringing the right people in contact with each other. The spin-offs, GTM and GlobalTechnics, can broker knowledge within and outside the (core) network.

Absorptive Capacity	Personnel transfer, graduating students	Buwe van Wimersma was transferred from SLC to Aérospatiale, in 1994 to study the application of Glare on the A330 and in 1997 to participate in the Large Aircraft division (for the A380). In 1993, Rob van Oost from SLC was sent to Boeing to study the application of Glare on the successor of the 747 Jumbo Jet, Tjerk de Vries, a Ph.D. student working on Glare from TU Delft went to Airbus; in addition, many graduates from TU Delft went to aerospace companies.
Printed and electronic media	Information systems, reports, publications	Common e-mail systems; data-links for the design of the Glare parts of the A380 between Fokker AESP and Airbus; 200 test reports with results for 'basic Glare'; a stress manual for Glare, written by people at GlobalTechnics and used within Airbus. dissertations from TU Delft; graduation reports from TU Delft; journal articles from researchers at TU Delft.
Goal alignment	Shared goals, demarcation, guidance of industry	Shared goal: application of Glare on the A380 of the Demarcation responsibilities and work fields between NLR and TU Delft. Priority setting of Airbus and Fokker for TU Delft.

Agreements on Value Distribution: Protection and Creation of Commitment

Another important solution concept that can shed some light on the dynamics of the development of Glare concerns the rules and agreements in the Glare network. Over time, several formal agreements were made. These rules and agreements had the positive effect that they created commitment to sharing knowledge, but on the other hand knowledge-sharing with excluded parties became more limited. For example, TU Delft made agreements about intellectual property and funding with Akzo, Alcoa and 3M. These agreements solidified the commitments of Akzo, Alcoa, and 3M to the development of FMLs. But these agreements also had an opposite effect: they restricted knowledge-sharing with partners in the periphery of the core network, like Marissen working for DFVLR in Germany.

The positive effect of agreements is also illustrated by the agreed joint venture of Akzo and Alcoa: SLC. This agreement proved to be effective in support of knowledge-sharing when Alcoa wanted to get rid of Glare. Because Alcoa had an agreement with Akzo, ending the involvement would have had legal consequences. Therefore, Alcoa was urged to find a better way out, which created the chance to keep Glare in The Netherlands. Otherwise, Alcoa would probably have put the Glare patents and knowledge on a shelf, thus restricting further development and knowledge-sharing.

Direct Communication

Meetings were an effective means of direct communication between representatives of network partners. Different kinds of meetings existed: site visits, training sessions, discussion meetings, (co-located) team working, conferences and social events. Each had their own effectiveness, frequency and attendees. Site visits were effective and efficient because they enabled rich interaction (live), provided the complete context (e.g. production facilities, test set-up) and also enabled knowledge-sharing in a protected situation. For example, with the barrel test, visiting engineers from NLR had a chance to see the whole test and set-up. If they had not visited the test, this knowledge would not have been shared.

Meetings were a standard way of knowledge-sharing throughout the development trajectory. In the 1980s and at the beginning of the 1990s, there was no formal network-wide consultative structure. From the inception of the research programmes (GTP, GRP), frequent meetings were held with the different parties and at different levels. These meetings were effective in reducing conflicts through trust-building, in dealing with motivation issues by creating commitment, and in increasing knowledge-sharing efficiency

through providing a rich knowledge channel. Not all parties were as motivated to attend these meeting and contribute, which in some cases led to frequently changing representatives in the meetings. This was not conducive to knowledge-sharing. A context-specific kind of meeting was the (academic) conference. Such conferences were effective at sharing knowledge, creating interest in prospective partners, sharing beliefs, building new relationships and creating a network identity.

Network Density

Knowledge brokers were an effective solution, especially for creating network density and thus tackling the efficiency and boundaries problems. Two types can be distinguished: the formal, institutionalized knowledge broker; and the informal knowledge broker. The first type is represented by the research group at TU Delft, later SLC and FMLC. In the cooperation with Airbus, there were also formal knowledge brokers: contacts that brought people from Fokker AESP and Airbus together.

The second type, the informal knowledge broker, is represented by informal contacts (interpersonal relationships) and 'spin-offs'. These 'spin-offs' were especially efficient at overcoming the knowledge protection issue. GTM, which consists of people who worked at FMLC and SLC, is now more able to share knowledge with different clients and less tied to protective measures of other partners.

Absorptive Capacity

Through the exchange of people between network partners absorptive capacity was created in the network. Boundaries are bridged and people become more motivated because of shared passions. It also provides a means for context-rich personal interaction, thus enabling efficient knowledge-sharing. Two instances of personnel exchange are found, the 'normal' exchange of people between organizations for a certain time period, like van Wimersma and Wit, who were stationed at Airbus France for a period of time. A second form of personnel transfer is the 'swarming out' of graduating students from the structures group at TU Delft. They acquired knowledge in the curriculum, often wrote a thesis on FMLs and sometimes stayed one or two years at the faculty to perform testing. When they subsequently moved to an employer in the aerospace industry, they brought with them their knowledge, contacts and enthusiasm. This created motivation and channels to find and share knowledge more efficiently.

Besides the efficient knowledge-sharing and the motivation effect, personnel exchange was also effective at crossing knowledge protection barriers

(similar in effect to site visits) and dispersing knowledge, thus establishing more common knowledge, creating absorptive capacity.

Printed and Electronic Media

Codified knowledge can be transferred through reports and information systems. This creates knowledge-sharing opportunities, thus providing a solution to the efficiency problem. Reports consisted mainly of test reports, handbooks and publications. The effectiveness of reports and publications depended on the context. Because publications contained more information than the parties actually needed, the knowledge was sometimes not used very effectively. Knowledge-sharing via reports and publications was especially efficient when the receiving party had a question that was answered in the report.

With the development of information technology, information systems were more often used to share information and codified knowledge. In the last phase, when Airbus was heavily involved, special data links were used for engineering and design, besides regular systems such as e-mail. But, in general, the use of special information systems was very limited.

Goal Alignment

This solution concept can be split into three: decisions about the demarcation of the work area, shared goals and focus of the industry. First, demarcation was useful to create clear understandings of each other's tasks, thus reducing possible competition conflicts. At one time, there were tensions between NLR and TU Delft about doing materials tests and building a test lab at Delft. They dealt with this issue by making arrangements about the demarcation of tasks.

Second, the common goal of the Glare project and especially of the research programmes was to get the material applied to an aircraft. This common goal was beneficial and attractive to all partners and thus provided the basis for motivation. This common goal ensured that the different individual goals of the partners never dominated, which would probably have resulted in the end of the cooperation. However, the knowledge-sharing was to some extent restricted by the different goals. Partners were not always willing to cooperate entirely, because they had different interests or priorities. This caused inefficiency, delayed the development process and reduced the motivation of other partners.

Third, at an industry level a more efficient allocation of research funding could have been achieved by a greater focus. Focus only emerged when Airbus became fully involved. From then on research was carried

out which was more closely adapted to the needs of a specific partner, Airbus.

Relationships between Solution Concepts and Problems

We will complement the overview of problems and solution concepts with Figure 8.5 which summarizes the insights and relationships discussed. This figure is built upon the interview data. We carefully analysed the frequency with which solution concepts, problems and relationships between them were mentioned.

DISCUSSION AND CONCLUSIONS

Our analysis provides a number of interesting insights. First, it is striking that free-riding appeared not to be a problem in the Glare network. Although it is a decentralized network, without a central orchestrator, none of the parties displayed free-riding behaviour. The long-term scope of the network may have prevented free-riding. At particular moments, a situation of free-riding seems to appear, but this is quickly corrected by other partners. And considering the whole time span, more or less opportunistic behaviour by a partner at one point in time is balanced by a lot of collaboration at another time. Second, this study showed interesting evidence of the importance of informal mechanisms in a decentralized network, but also demonstrated the vulnerability of these informal means (e.g. to personnel change and disagreements). Another important finding was the effectiveness of agreements on value distribution. On the one hand, this solution concept constitutes trust and commitment, thus enabling knowledge-sharing. On the other hand, agreements on value distribution can also limit knowledge-sharing and reduce absorptive capacity. Hence, some solution concepts may have drawbacks. Furthermore, the Glare case also made clear that more solutions are not always better. Some solutions are more applicable in some networks than in others.

Regarding knowledge types, the case analysis shows that it is harder to share core and tacit knowledge than non-core and explicit knowledge. For example, the knowledge regarding specific Glare properties was difficult to share. Sharing core knowledge increased the motivation problem, because (industrial) partners wanted to protect this knowledge. But also at an individual level, people were sometimes not willing to share their core knowledge because of personal pride. The protection problem was reduced by creating more commitment by formal agreements. Informally, interpersonal relationships, meetings, and site visits were very important to sharing

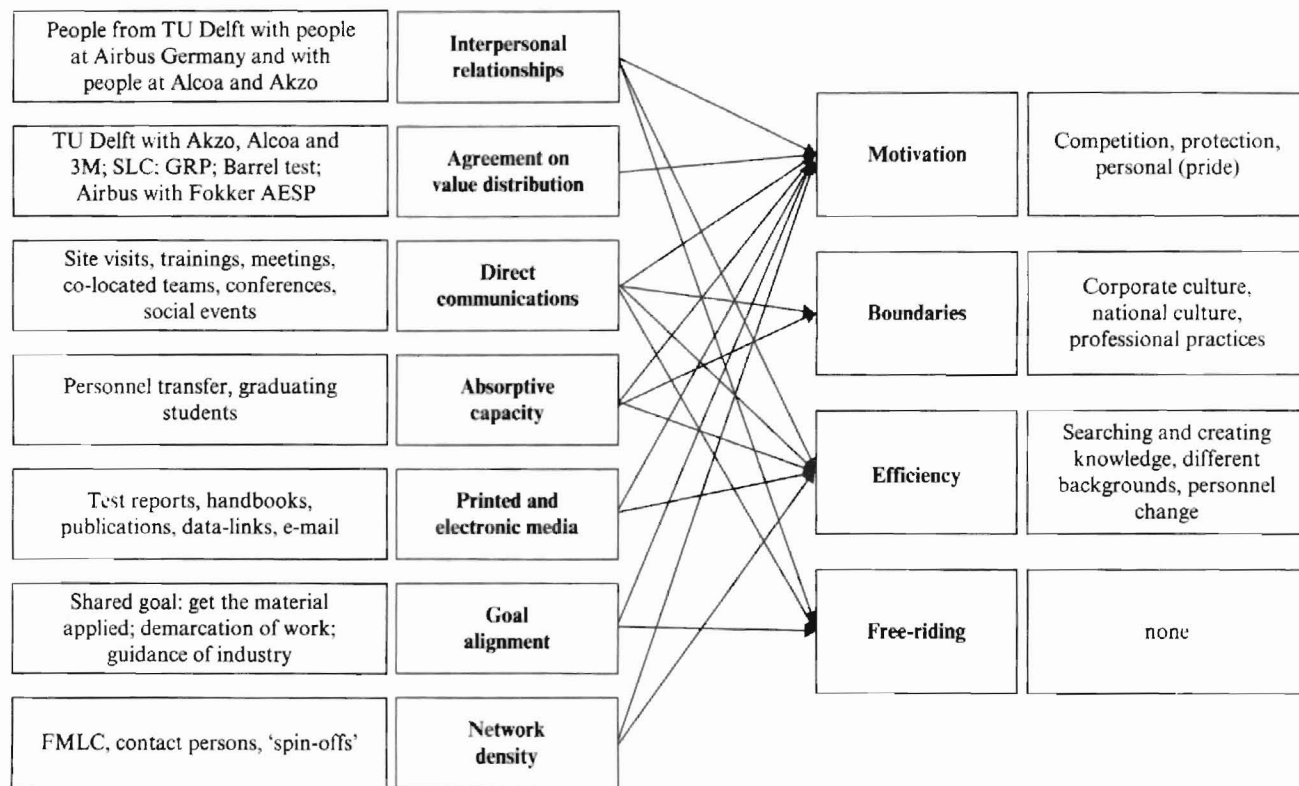


Figure 8.5 Solution concepts in relation to knowledge-sharing problems

core knowledge. The latter three solutions have the advantage that they also provide an opportunity for sharing tacit knowledge. Sharing this (highly) tacit knowledge requires absorptive capacity. But in the Glare case, a common knowledge base was often absent and Glare's development was slowed down by protective measures.

Considering network types, the Glare network could be characterized as a decentralized, continuous, international network focused on a single innovation. In a decentralized network, few central solutions can be applied, and commitment to knowledge-sharing cannot be enforced. Thus, informal and decentralized solutions, like interpersonal relationships and direct communications, were extremely important for knowledge-sharing. Fortunately, because the cooperation spanned a long time period, a bigger structure could emerge from local solutions. Central teams like the GRP teams were founded, which was possible because there was funding, support and commitment. Also the function of the knowledge centre could become more formalized in the founding of FMLC by three network partners (NLR, TU Delft, Stork Fokker AESP). These new entities at the core of the network never fulfilled the role of network orchestrator, however, and could not exert any power over the other network partners.

Explorative innovation is surrounded by uncertainty, as the Glare story clearly shows. There was uncertainty in the application of the material, uncertainty regarding the involvement of network partners and often it was uncertain whether the material would ever be successful. The indefinite time frame and the unknown obstacles in the development path were the reasons why industrial partners lost motivation when clear progress and application opportunities were lacking. That Glare, however, became successful is largely a result of the perseverance of a limited group of 'believers' combined with the appearance of an application opportunity in which the advantages of Glare were recognized.

Was it necessary that this process took 30 years? Perhaps not, but things always look simpler in hindsight. The development and application of Glare was bounded by many constraints that could not easily be changed, like funding possibilities, application possibilities and the time needed for the acceptance of a fundamentally new material in a community already divided by the battle between the aluminium engineers and the composite engineers. Moreover, in the aircraft industry, introductions of completely new large aircraft are few and far between. The Airbus A380 was the first aircraft where Glare could be applied on a large scale. There were a number of other possibilities, but for various reasons Glare was not adopted in those designs. Two of our respondents discussed this issue and said: 'We are talking about a situation where facts and relationships have to come together. If we did not have a good relationship with Airbus, Glare would

have never been applied on this plane.' 'But maybe on the Boeing 787 instead . . . ' 'Or neither. It depends on a good product and on having good relationships. If one of these is lacking, nothing happens.'

The continuity of the network bounded opportunistic behaviour by parties. There were always one or more network partners who saw the long-term benefits of continued cooperation and knowledge-sharing. Even when certain parties temporarily withdrew (Fokker) or permanently left the network (Akzo), other parties saw room for continuity. The fact that the network was dispersed across national borders and continents did not make knowledge-sharing easier, but good personal relationships and frequent meetings between a core group of individuals kept all major network partners involved and 'in the loop'.

It is precisely this passion for fibre-metal laminates shared by a select number of individuals that has eventually landed Glare on the Airbus A380. Knowledge-sharing and cooperation in the network have been a struggle at times, but by the conscious and, more often, subconscious application of various solution concepts, the knowledge-sharing problems of motivation, free-riding, efficiency and boundaries were overcome. Eventually, 30 years of passionate work on an essentially Dutch invention connected with a window of opportunity in the fiercely competitive battle between the two aerospace giants in the world.

SUMMARY

This case study describes the development of the new aircraft material Glare in an international network. After 30 years of development, this new material was finally applied on a large scale, on the Airbus A380. Regarding knowledge-sharing, it becomes clear that motivation may be an important challenge in a decentralized network where knowledge is shared with high tacitness and coreness. It is striking that the free-riding dilemma was not found, probably because the continuity of collaboration bounded opportunistic behaviour by network members. In the Glare case, knowledge-sharing was managed by a number of means, most of which were applied more or less unconsciously. The three most important solutions were: (1) interpersonal relationships, which were very important in motivating partners; (2) rules and agreements, which were important in creating commitment to engage in development; and (3) meetings, which were important in establishing interpersonal relationships and which served as opportunities to share knowledge.

NOTE

1. For this case study, two data sources were used: interviews and documentation. The interviews sought to uncover multiple understandings of the same phenomena. Eighteen interviews were conducted; interviewees were selected such that all the main network players were represented. These semi-structured interviews lasted 1.5 hours on average. All interviews were recorded and fully transcribed. Subsequently, the transcription was checked with the interviewee. Complementary documentation consists, first, of the book *Glare: History of the Development of a New Aircraft Material*, written by Ad Vlot (2001). More information about the development of Glare is found in *Around Glare: A New Aircraft Material in Context*, edited by Coen Vermeeren (2002). A third source of information is the 19th Plantema Memorial Lecture by Boud Vogelesang (2003). Furthermore, different kinds of additional documentation were collected: dissertations, newspaper articles, public interviews, project documentation and patent databases. These sources were used to prepare for the interviews and as a means of interpreting, checking and enriching interview findings.

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